USE OF CALORIC TEST IN EVALUATING THE EFFECTS OF GRAVITY ON CUPULA DISPLACEMENT

Michael E. McLeod and Manning J. Correia

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Research Report

USE OF CALORIC TEST IN EVALUATING THE EFFECTS OF GRAVITY ON CUPULA DISPLACEMENT*

Michael E. McLeod and Manning J. Correia

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SUMMARY PAGE

THE PROBLEM

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This study was carried out to evaluate the effect of gravity on cupula displacement.

FINDINGS

The results of this study do not support the hypothesis that the cupula responds to linear acceleration (gravity) if it is assumed that the cupula is heavier than the surrounding endolymph.

Author

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INTRODUCTION

The classical concept of division of labyrinthine function, in which the semicircular canals were considered to be sensitive only to angular acceleration and the otolith organs sensitive only to linear acceleration, has been challenged in recent years. Benson and Whiteside (1), ter Braak (4), Gernandt (6), deKleyn and Magnus (7), and Lorente de Nó (8) have attempted to show through experimental and morphological evidence that the semicircular canals act as linear, as well as angular, accelerometers.

In the human centrifuge an individual can be subjected simultaneously to angular and linear acceleration. Benson and Whiteside (1) increased linear acceleration up to 3.1 g and observed significant reductions in nystagmus associated with increasing linear accelerations. They concluded that the modified response was due to the interaction of linear and angular acceleration on the horizontal semicircular canals or the interaction of the otolith organs with the semicircular canals. Gernandt (6), using a turntable, recorded from the vestibular branch of the eighth cranial nerve in cats. He observed regular changes in the response from the horizontal canal as the distance between the subject and the center of rotation was increased.

deKleyn and Magnus (7) argued that the structural continuity between the endolymphatic spaces of the semicircular canals and the sacculi necessitates response of the semicircular canals to linear acceleration. Lorente de Nó (8) speculated that the membranous canals within the bony labyrinth are mobile, and linear accelerations produce displacement of the canals and resulting stimulation of the canal crest (crista).

ter Braak (4) calculated that a difference in specific weight of .0001 between the cupula and the surrounding endolymph would allow stimulation of the semicircular canals by a linear acceleration of 981 cm/sec^2 (gravity), assuming the direction of acceleration to be at right angles to the longitudinal axis of the crista-cupula.

Rather than varying the magnitude of linear acceleration on a rotary-induced cupula displacement, another approach might be to maintain magnitude of linear acceleration constant and vary the direction of cupula displacement. This end may be achieved by varying the direction of cupula displacement using hot and cold caloric stimulation and varying the direction of the gravity vector on the cupula displacement arc by testing the subject in the supine and prone positions.

This study was conducted to determine if caloric-induced cupula deflections would be influenced by linear acceleration (gravity).

PROCEDURE

SUBJECTS

Sixteen men between the ages of 18 and 21 served as subjects. Each subject was considered to have normal labyrinthine function on the basis of a complete ENT evaluation.

APPARATUS

The apparatus consisted of a constant temperature circulator, a thermistor, and a telethermometer. The Bronwill Constant Temperature Circulator was used to maintain the water bath temperature constant; a thermistor was used in the tip of the irrigating nozzle to detect the water temperature as it left the end of the irrigating tube; and a telethermometer recorded the thermistor temperature to the nearest 0.2 degree Centigrade. The nozzle tip was 1 mm. in diameter and delivered a water volume of 100 cc. during forty seconds of irrigation.

Horizontal nystagmus was recorded on a Sanborn polygraph by means of the corneo-retinal potential technique. To assure that only horizontal nystagmus was being produced, vertical eye movements were recorded in eight of the sixteen subjects. No vertical nystagmus was observed.

METHOD

In this experiment each of sixteen subjects received two sets of four caloric irrigations, one set at an irrigating temperature of 44.0 degrees Centigrade and one set at an irrigating temperature of 30.0 degrees Centigrade. At each temperature both the right and left ears of each subject were irrigated as the subject lay in the prone position and in the supine position. A rest period of five minutes was allowed between each of the four irrigations within a set and a twenty-minute rest period separated the two sets. The variables, water temperature, body position, and irrigated ear, were counterbalanced to eliminate order effects.

When each subject was placed on the bed in the prone or supine position, his head extended beyond the bed and was supported by a headrest so that a line from the outer canthus of the eye to the tragus of the ear would be vertical. This positioning procedure insured that the horizontal semicircular canals were approximately in the vertical plane during all caloric irrigations. Before and after each caloric irrigation, 20-degree eye movement calibrations were obtained. On every irrigation the thermal stimulus was delivered against the ear drum for a period of forty seconds. Ten seconds prior to the cessation of stimulation, the subject was given a mathematical problem to maintain alertness, all lights were turned off, and the recorder was started. The entire nystagmic response to each irrigation was recorded. During the recording period, the subject's eyes were open and to eliminate all possible source of light, a mask was utilized in addition to the room being completely dark.

RESULTS AND DISCUSSION

The magnitude of the entire nystagmic response following cessation of thermal stimulation for each subject under each experimental condition of this study was calculated in terms of average slow phase eye velocity (degrees/second), and the results are presented in Table I. The average slow phase eye velocity was calculated by dividing the total slow phase eye displacement (in degrees) by the total duration of the nystagmic response.

A variance analysis of the data presented in Table I was performed and the results are shown in Table II.

In Figure 1 the average slow phase eye velocity in degrees per second for all subjects is plotted for each five-second interval following cessation of caloric stimulation. Plots for all subjects in both the prone and supine positions are presented in the figure, and each point on the plots represents the mean slow phase eye velocity of 64 scores, one score for both 30 and 44 degree water temperature on both the right and left ear of the sixteen subjects.

The exact orientation of the cupula relative to the horizontal semicircular canal assumes importance in the study of the interaction of the gravity vector on cupula displacement. It appears from observation of a horizontal cross section of an adult temporal bone (12) that the ampulla is located in the anterior half of the horizontal semicircular canal, and the crista-cupula protrudes posteriomedially from the anterolateral wall. The cupula which may be considered as an extension of the crista thus seems to be approximately parallel to the sagittal plane of the body. In Figure 2* a similar cross section of another adult temporal bone illustrates the position of the crista. In this case, it forms an angle of approximately 10 degrees with the sagittal plane. The crista-cupula, then, is located in the anterior half of the semicircular canal, occupies the outer wall of the canal, is directed posteriomedially, and forms an angle from approximately 0 - 10 degrees with the sagittal plane.

To allow for individual anatomical variations and ambiguity as to the exact cupular location, the cupula was arbitrarily assigned five possible positions with reference to the sagittal plane. The estimated influence of gravity on these various

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Table I

Average Slow Phase Velocity (Degrees/Second) for Each Subject and All Subjects

Combined under Each Experimental Condition

	Prone				Supine			
	Left Ear		Right Ear		Left Ear		Right Ear	
Subject	30°	44°	30°	44°	30°	44°	30°	44°
Tho, A.	1.3	2.6	1.7	2.5	14.7	10.3	10.6	8.0
Tho, D.	4.0	4.2	3.6	3.4	7.3	5.9	7.6	6.5
Du	1.4	4.5	0.9	2.3	6.7	10.8	9.0	10.0
Ko	4.2	2.4	4.7	5.2	2.4	6.0	7.0	6.1
Al	1.8	5.3	5.4	4.2	6.0	11.3	9.3	12.3
Jo	3.7	4.2	5.7	4.2	7.8	6.1	5.1	6.6
Di	8.8	5.7	4.4	4.0	13.6	18.3	13.1	14.8
Po	8.9	3.7	6.1	8.0	6.4	10.8	8.8	11.9
Ov	6.9	2.5	3.3	4.4	5.5	3.1	6.2	8.7
Tho, R.	7.7	4.2	4.2	3.4	10.1	13.5	10.8	11.0
St	3.7	2.3	2.4	2.1	4.5	7.8	8.3	4.5
Le	1.1	4.8	2.7	4.2	3.2	7.7	5.3	5.6
To	16.4	12.3	15.8	12.0	16.0	28.2	22.8	26.6
Va	2.8	2.9	4.2	1.7	6.6	6.4	5.6	9.3
Gi	3.9	2.7	6.1	4.1	10.7	16.1	6.3	12.7
Ha	1.9	0.7	1.7	2.8	11.0	12.0	6.9	9.0
$\bar{X}$	4.9	4.1	4.6	4.3	8.3	10.9	8.9	10.2

Table II

Variance Analysis of Slow Phase Eye Velocity

Source of Variation	Sum of Squares	d.f	Mean Square	F.
Position	841.53	1	841.53	22.36*
Ear	0.05	1	0.05	
Temp.	15.68	1	15.68	
Position x ear	0.02	1	0.02	
Position x temp.	50.75	1	50.75	1.35
Ear x temp.	1.09	1	1.09	
Position x ear x temp.	7.03	1	7.03	
Within treatments	2107.78	56	37.64	
Total	3023.93	63		

* $P < .001$

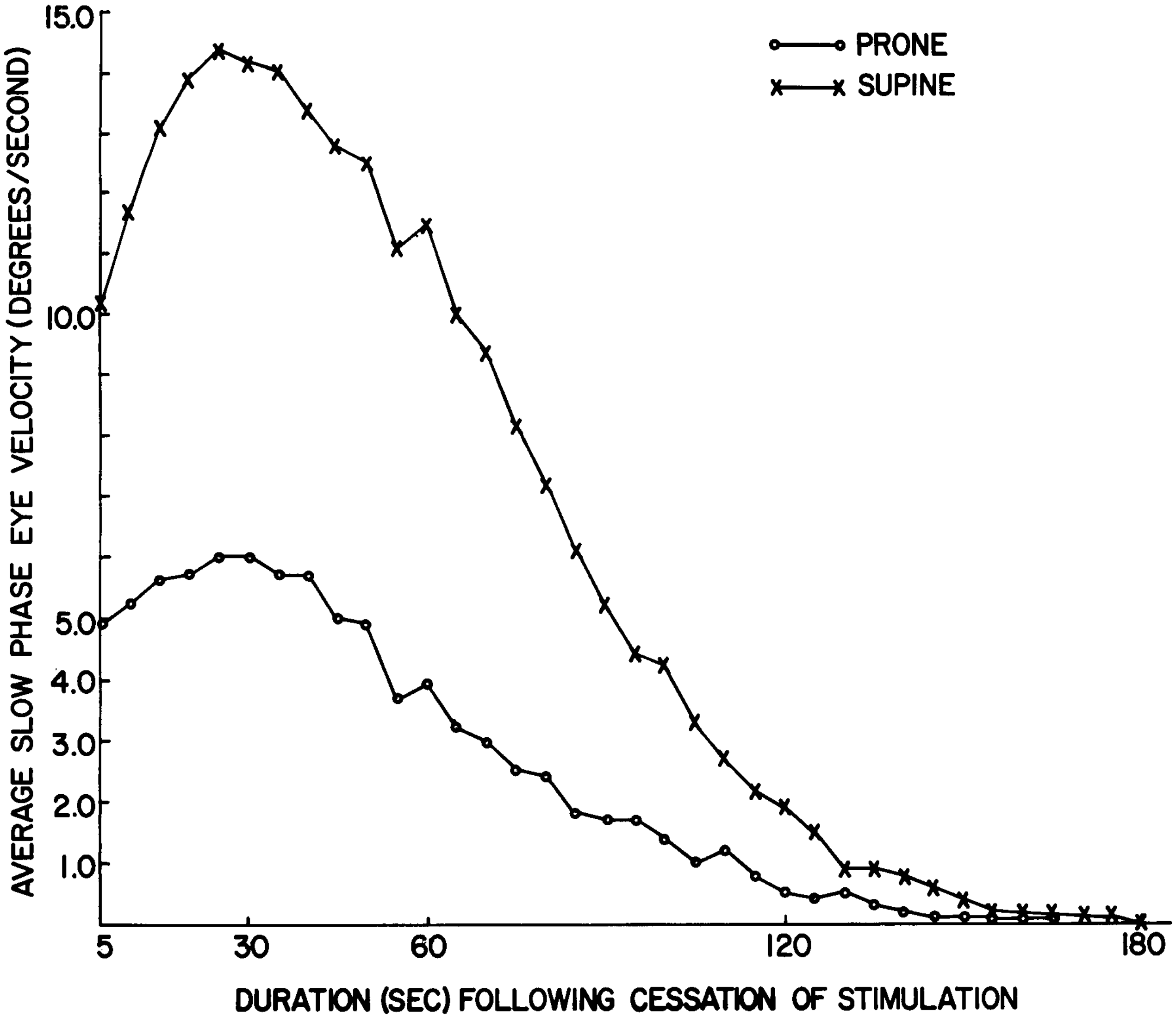


Figure 1

Average Slow Phase Eye Velocity (Degrees/Second) As a Function of Time (in Seconds) Following Cessation of Caloric Stimulation for the Prone and Supine Body Positions

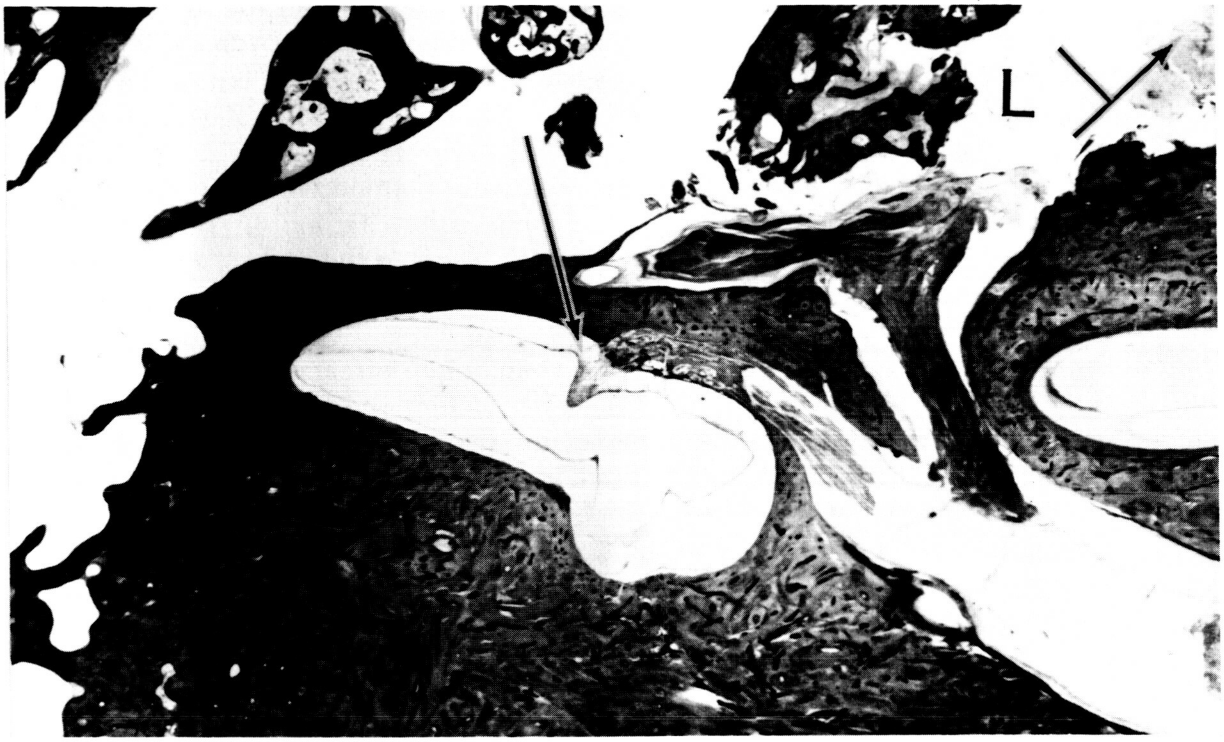


Figure 2

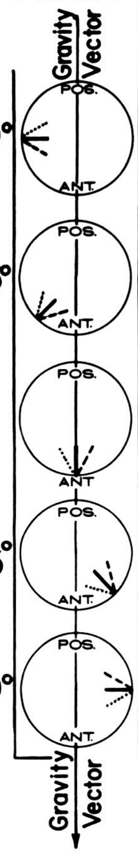
Horizontal Cross Section of Left Temporal Bone of an Adult. The Short Arrow Is in Sagittal Plane, Parallel to Nose, and Points Anteriorly. Large Arrow Originating in Middle Ear Points to Crista of Left Horizontal Semicircular Canal.

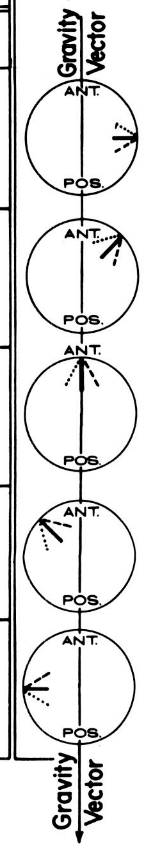
cupula positions and the predicted relations between nystagmus output for prone and supine body positions are presented in Figure 3. The predictions presented in Figure 3 are based on the assumption that the cupula is heavier than the surrounding endolymph. For example, if it is assumed that the cupula is parallel to the sagittal plane (0 degree cupula position, Figure 3), cupula deflection in either direction would be prolonged by gravity while the subject lay in a prone position, and in the supine position the return of the cupula would be enhanced by the gravity vector. Thus, if nystagmus is related to the magnitude of cupula displacement and/or speed of cupula return, then in all five possible cupula positions presented in Figure 3 the caloric responses in the prone position should always equal or exceed the caloric response in the supine position. However, in this experiment the opposite result was obtained. From Table II and Figure 1, it is observed that the magnitude of the response in the supine position was significantly greater than the prone response ($F=22.36$, d.f.$=1/56$ $P < .001$).

The reason for the disparity in the caloric responses obtained in the prone and supine positions is not readily apparent, but several possibilities exist. The significantly greater caloric response observed for individuals in the supine, as opposed to the prone, position may be due to the cupula being lighter than the surrounding endolymph, an interaction of canicular sensory information and sensory influx from the otolith organs, the neck muscles, or direct temperature effects of caloric stimulation on the crista of the semicircular canals. The predictions presented in this study were based on the assumption that the cupula was heavier than the surrounding endolymph. However, the cupula may be equal to or lighter than the endolymph. If the cupula and endolymph were of the same density, then there should be no difference between nystagmus of subjects in prone and supine body positions. If the cupula was lighter than the surrounding endolymph and approximately in the sagittal plane, then the results obtained in this study would conform to the prediction that nystagmus should be greater in the supine body position.

Several authors (1, 10) feel that the otolith organs may exert a modifying influence on the response of the semicircular canals. It is possible that gravity acts differently on the maculae of the utricle or saccule in the prone and supine position, and because of an otolith-semicircular canal interaction, alteration of the caloric-induced nystagmus would result. This might be reflected in suppression of horizontal nystagmus in the prone position.

Impulses from the posterior cervical roots may play a role in modifying the caloric-induced nystagmus. Philipszoon (11) has elicited positional nystagmus in rabbits by cutting the posterior cervical roots, Barany (2) by cervical torsion, and Bos (3) has shown that nystagmus produced by cervical torsion can be modified by simultaneous labyrinthine stimulation. In this experiment no neck torsion was produced, and it would seem unlikely that the difference in proprioceptive impulses in the prone and in the supine position would be responsible for the differences found.





	PRONE BODY POSITION				SUPINE BODY POSITION			
	LEFT EAR		RIGHT EAR		LEFT EAR		RIGHT EAR	
	30°	44°	30°	44°	30°	44°	30°	44°
+90°	P = S	P = S	P = S	P = S	P = S	P = S	P = S	P = S
+45°	P ≥ S	P ≥ S	P ≥ S	P ≥ S	P ≥ S	P ≥ S	P ≥ S	P ≥ S
0	P > S	P > S	P > S	P > S	P > S	P > S	P > S	P > S
-45°	P ≥ S	P ≥ S	P ≥ S	P ≥ S	P ≥ S	P ≥ S	P ≥ S	P ≥ S
-90°	P = S	P = S	P = S	P = S	P = S	P = S	P = S	P = S

LEGEND:

P = PRONE
S = SUPINE
ANT. = ANTERIOR
POS. = POSTERIOR

--- CUPULA DEFLECTION WITH 30° IRRIGATING TEMPERATURE
.... CUPULA DEFLECTION WITH 44° IRRIGATING TEMPERATURE
— RESTING POSITION OF CUPULA

Figure 3

Predicted Relationships of Nystagmic Output in Prone and Supine Body Positions Assuming Gravitational Influence on Cupula Displacement. Five Cupula Positions Represented. These Cupula Placements Represent Arbitrary Positions of Cupula with Respect to Sagittal Plane.

A fourth possibility is the effect of temperature on the horizontal canal crista. When 3 degrees Centigrade irrigating temperature was used, caloric-induced nystagmus was observed in squirrel monkeys in which the semicircular canals were surgically blocked. This procedure left the crista-cupula intact but prevented endolymph flow (Money, personal communication). The animals did not respond, however, to angular acceleration, and the caloric-induced nystagmus was not gravity dependent, failing to reverse when the animal was rotated 180 degrees to the prone position. The nystagmus could be reversed using a hot caloric stimulus of 47 degrees Centigrade. This suggested that the nystagmus did not result from cupula displacement but possibly from the local effect of temperature on the crista, resulting in a change in the resting discharges (9) from the intact crista. It is possible (Money, personal communication) that the effect of temperature on the crista by increasing or decreasing resting discharges would enhance the effect of cupula deflection on these discharges in the supine position and counteract the effect in the prone position. Consequently, nystagmus would be greater in the supine position.

Another interesting finding in this study is that the nystagmic response to hot caloric irrigation was greater than to cold caloric irrigation in the supine position, but the opposite was true in the prone position. These findings are consistent with a greater nystagmic response produced by ampullopetal endolymph flow as predicted by Ewald's first law (5), and further investigation of these findings is in progress.

The results of the present experiment reveal a significantly greater caloric-induced nystagmic response when an individual was tested while lying in a supine body position as opposed to a prone position. This makes suspect the contention that the semicircular canals are affected by gravity if it is assumed that the cupula is heavier than the surrounding endolymph. However, the data of this study support the concept that the semicircular canals respond to linear acceleration if the cupula is considered to be lighter than the surrounding endolymph.

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